MEMORANDUM

November 9, 2004

FOR: FCRPS Remand File

FROM: Chris Ross, Paul Wagner

SUBJECT: Analytical Approach and Method Used to Calculate Pool Survivals and Develop a Flow/Survival Relationship for Snake River Salmon and Steelhead

Snake River Spring/summer Chinook Salmon

An analysis was conducted to develop a quantitative relationship between flow and reservoir pool survival for listed spring chinook salmon stocks. The method consisted of examining the relationship between pool survivals and flows for both the Snake River reach (Lower Granite to Ice Harbor Dam) and the lower Columbia River reach (McNary to Bonneville Dam). Only empirically derived reach survival estimates were used over the 1994-2003 study period. The pool survival data were derived from a retrospective SIMPAS modeling analysis (Table 1). For each year, route-specific historic dam passage and survival data were used to determine the individual dam survivals for that year. Dividing the empirical reach survival for each project by the dam survival provided a year-specific pool survival estimate for each project.[1]

Table 1. Retrospective pool survivals and flows by year with bolded survival values based on empirical data.

Pool Survivals - Yearling Chinook Retro Analysis

Project	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
LGR	**0.9675**	**0.9387**	**1.0000**	**0.9519**	**0.9499**	**0.9639**	**0.9538**	**0.9790**	**0.9954**	**1.0000**
LGS	**0.8496**	**0.9036**	**0.9355**	**0.9522**	**0.9969**	**0.9616**	**0.9499**	**0.9696**	**0.9589**	**0.9582**
LMN	**0.9200**	**1.0000**	**0.9934**	**0.9562**	**0.9170**	**0.9951**	**0.9482**	**0.9149**	**1.0000**	**1.0000**
IHR	0.9079	**0.9872**	**0.9052**	**0.9297**	**0.9955**	**0.9896**	**0.9870**	**0.8827**	**1.0000**	**0.9990**
MCN	0.9139	**1.0000**	**0.9297**	**0.9532**	**1.0000**	**1.0000**	**1.0000**	**0.9322**	**0.9549**	**1.0000**
JDA	0.7735	0.8794	0.8531	0.8462	**0.8610**	**0.8977**	**0.9413**	**0.8325**	**0.9495**	**0.9369**
TDA	0.9161	0.9539	0.9448	0.9424	0.9503	**0.9976**	**0.9160**	**0.8968**	**1.0000**	**1.0000**
BON	0.8348	0.9004	0.8845	0.8803	0.8941	**0.9625**	**0.8844**	**0.8508**	**0.9589**	**0.9445**
Observed seasonal average flows for each reach:										
LSN	58	97	138	158	112	116	84	43	80	89
LCO	186	249	360	441	285	303	254	120	277	242

[1] The year 1997 was removed from the flow/survival analysis because high levels of debris at the dams occurred that year, which decreased juvenile fish survival at the dams but not necessarily in the pools. Since pool survival is derived from the reach survival estimate (tailrace to tailrace), which includes the dam, exclusion of the year 1997 was deemed appropriate.

The Snake River and lower Columbia River reach pool survival estimates were determined as the product of the four pool survivals of the respective project reaches. Flows used in the retrospective analysis were observed seasonal average flows for the years 1994-2003. Flows used in the proposed and reference operations were developed through hydrologic modeling using BPA's HYDSIM model. A regression analysis was performed using PRISM software to develop a relationship between the seasonal average flows and the composite pool survival values for each reach (Figure 1). For both the Snake River and lower Columbia River reaches, the best fit curve was a one-phase exponential association. This curve passes through 0,0 in the regression, consistent with the assumption that zero flow equals zero survival. Several commenters indicated that the Snake and Columbia Rivers never have zero flow – this is true. However, zero flow would not provide survival of juvenile anadromous fish to the ocean and, thus, is considered to be a valid part of the relationship. Also, the curve is not extended outside the range of empirical data to zero survival. . The shape of the curve indicates a reduction in the rate of increasing juvenile fish pool survival with higher flows, consistent with other analyses (Williams et al. 2004). Several commenters indicated that the year 2001 data point is "arbitrary." The 2001 pool survivals were obtained from empirical reach survival estimates of each species measured in 2001.

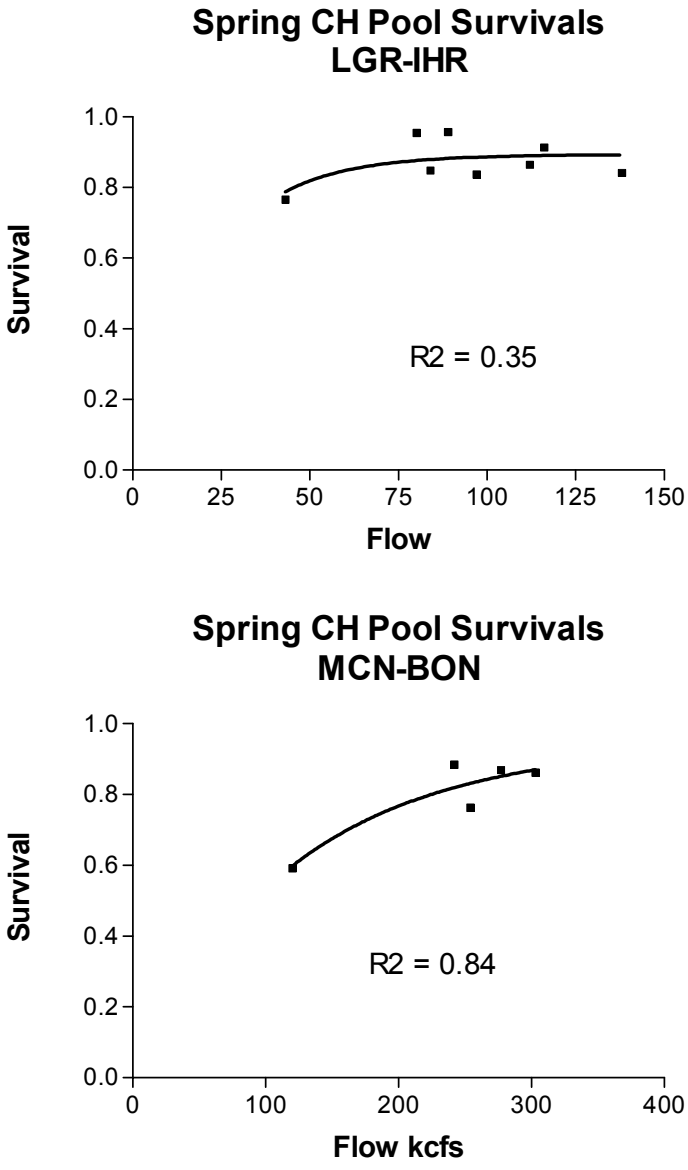


Figure 1. Relationship between flow and pool survival for juvenile spring chinook salmon through Lower Snake and Columbia River reaches.

One commenter suggested regressing water particle travel time (WPTT) on pool survivals instead of flow. Since reservoir volume divided by flow equals WPTT in days, and reservoir volume is constant, flow is inversely proportional to WPTT in the juvenile migration corridor of the FCRPS. WPTT regressed on pool survivals for several reaches for different species indicated a change in the scalar orientation of the values on the X axis, the values closer together and a greater distance between the low value of 2001 and the other WPTT values. The regressions indicated a reduction in survival either at the high end of the gap in data or at the low end, neither of which is known (Figure 2). A more gradual change in survival across the range of missing data was deemed preferable given other flow/survival analyses with gradually changing relationships (Williams et al., 2004). Therefore, NOAA staff retained the use of flow as the environmental variable in the analysis.

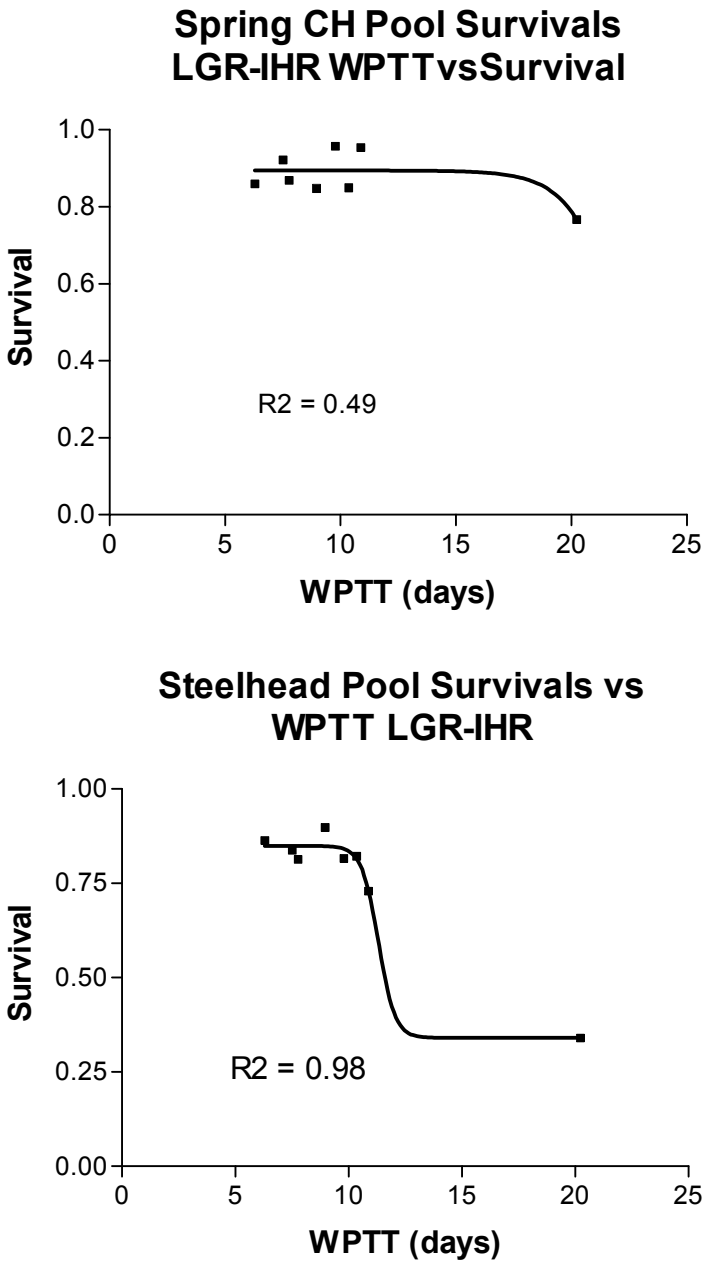


Figure 2. Relationship between water particle travel time (WPTT) and pool survival for juvenile spring chinook salmon and steelhead through the Lower Snake River reach.

The steps used to conduct the analysis follow the sequence of columns in Table 2. The sequence of calculations was:

1) Using the curve fitting function described above, annual juvenile spring chinook reach survival estimates (pools only) were calculated for both the proposed flows and reference flows for the lower Snake River and lower Columbia River reaches.

2) Individual pool survival estimates were obtained from the respective reaches by taking the fourth root of the reach survival estimates.

3) The annual proposed operation pool survivals were divided by the retrospective pool survivals and the reference operation pool survival values divided by the proposed hydro operation pool survival values to obtain adjustment factors for use in SIMPAS pool survivals in the gap analysis.

Table 2. Flow and estimated survivals (pools by reach and individual pools) of juvenile spring chinook by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches. (An adjustment to flow was made by operating the LCO pools at minimum operating elevations for the reference operation.)

Spring Chinook **POOL SURVIVALS VS FLOWS** 10/27/04

Ex. Association Lower Snake (LSN)		**Ex. Association Lower Columbia (LCO)**	
YMAX	0.8928	YMAX	0.9457
K	0.04982	K	0.008338

	Retrospective		**Proposed**				**Reference**	
	Reach Survival							
Year	LSN	LCO	Flow LSN	Survival LSN	Flow LCO	Survival LCO	Flow LSN	Survival LSN
1994	0.692150	0.543197	56.03	0.838041	162.02	0.700763	60.73	0.849473
1995	0.887653	0.763792	93.60	0.884375	244.38	0.822441	95.69	0.885208
1996	0.844131	0.672588	125.12	0.891048	315.89	0.877800	126.32	0.891149
1997	0.887351	0.681586	145.37	0.892161	401.76	0.912517	147.77	0.892233
1998	0.794695	0.739117	105.29	0.888094	257.84	0.835527	107.51	0.888588
1999	0.818698	0.867273	112.74	0.889553	310.88	0.874904	114.52	0.889829
2000	0.822924	0.767611	80.02	0.876227	246.25	0.824348	82.84	0.878396
2001	0.340380	0.596996	53.99	0.832183	155.53	0.687143	56.74	0.839943
2002	0.715137	0.875424	84.80	0.879739	256.09	0.833907	86.50	0.880802
2003	0.810038	0.887674	73.32	0.869660	194.94	0.759557	76.52	0.873068

	Retrospective		**Proposed**	**Proposed**	**Reference**
Year	4^{th} Root LSN	4^{th} Root LCO	4^{th} Root LSN	4^{th} Root LCO	4^{th} Root LSN
1994	0.912116	0.858498	0.956789	0.914940	0.960036
1995	0.970646	0.934854	0.969748	0.952305	0.969977
1996	0.958523	0.905602	0.971573	0.967941	0.971600
1997	0.970563	0.908616	0.971876	0.977373	0.971895
1998	0.944170	0.927210	0.970766	0.956071	0.970901
1999	0.951220	0.965026	0.971165	0.967142	0.971240
2000	0.952445	0.936020	0.967507	0.952857	0.968105
2001	0.763820	0.879008	0.955113	0.910462	0.957332
2002	0.919596	0.967285	0.968475	0.955607	0.968767
2003	0.948694	0.970652	0.965689	0.933555	0.966634

Table 2. Flow and estimated survivals (pools by reach and individual pools) of juvenile spring chinook by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

	Ratio of Proposed to Retro (adjust. Factors)		**Ratio of Reference to Proposed (adjust. Factors)**
Year	Lower Snake	Lower Columbia	Lower Snake
1994	1.048978	1.065745	1.003393
1995	0.999075	1.018667	1.000235
1996	1.013614	1.068837	1.000028
1997	1.001352	1.075672	1.000020
1998	1.028169	1.031126	1.000139
1999	1.020968	1.002192	1.000078
2000	1.015814	1.017987	1.000618
2001	1.250443	1.035783	1.002323
2002	1.053152	0.987927	1.000302
2003	1.017914	0.961782	1.000978

Table 2. Flow and estimated survivals (pools by reach and individual pools) of juvenile spring chinook by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

Spring Chinook JR/CR

10/25/2004

Ex. Association

Lower Columbia		Pool	Avg normal	At MOP	Avg normal to MOP ratio:
		MCN	1300	1166	**1.142237**
YMAX	0.9457	JDA	2325	1990	
K	0.008338	TDA	318	277	
Half-Life	82.76	BON	795	715	
		LC Vol.(Kaf)	4738	4148	

Year	**Reference** Flows LCO	Adjusted LCO Flow	Adjusted Survival LCO	Adj Survival per mile LCO	Adj Survival MCN pool (32.3 miles)	Adj Survival JDA pool (76.4 miles)	Adj Survival TDA pool (24.1 miles)	Adj Survival BON pool (45.4 miles)
1994	161.39	184.34	0.742360	0.998330	0.947432	0.880092	0.960510	0.926908
1995	249.22	284.67	0.857608	0.999138	0.972542	0.936265	0.979440	0.961621
1996	324.57	370.74	0.902721	0.999426	0.981621	0.957072	0.986255	0.974264
1997	421.76	481.75	0.928668	0.999585	0.986676	0.968770	0.990042	0.981323
1998	272.17	310.88	0.874906	0.999250	0.976068	0.944315	0.982089	0.966526
1999	323.44	369.44	0.902254	0.999423	0.981529	0.956859	0.986186	0.974135
2000	256.18	292.62	0.863261	0.999175	0.973700	0.938906	0.980311	0.963232
2001	151.82	173.41	0.722959	0.998181	0.942895	0.870157	0.957076	0.920675
2002	269.32	307.63	0.872958	0.999238	0.975674	0.943413	0.981793	0.965977
2003	187.13	213.75	0.786577	0.998654	0.957420	0.902196	0.968055	0.940672

Table 2. Flow and estimated survivals (pools by reach and individual pools) of juvenile spring chinook by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

Year	Proposed Flows LCO	Survival LCO	Adj Survival per mile LCO	Adj Survival MCN pool	Adj Survival JDA pool	Adj Survival TDA pool	Adj Survival BON pool	Ref. survival ratio--MCN	Ref. survival ratio--JDA	Ref. survival ratio--TDA	Ref. survival ratio--BON
1994	162.02	0.700763	0.998007	0.937581	0.858601	0.953048	0.913390	1.010507	1.025031	1.007829	1.014800
1995	244.38	0.822441	0.998904	0.965189	0.919608	0.973910	0.951418	1.007618	1.018113	1.005679	1.010724
1996	315.89	0.877800	0.999269	0.976652	0.945653	0.982528	0.967339	1.005087	1.012075	1.003793	1.007158
1997	401.76	0.912517	0.999486	0.983543	0.961510	0.987695	0.976946	1.003185	1.007551	1.002376	1.004480
1998	257.84	0.835527	0.998992	0.967954	0.925853	0.975991	0.955252	1.008383	1.019941	1.006248	1.011802
1999	310.88	0.874904	0.999250	0.976068	0.944314	0.982088	0.966525	1.005595	1.013285	1.004172	1.007873
2000	246.25	0.824348	0.998917	0.965594	0.920522	0.974215	0.951979	1.008395	1.019972	1.006257	1.011820
2001	155.53	0.687143	0.997897	0.934251	0.851406	0.950522	0.908834	1.009252	1.022023	1.006895	1.013029
2002	256.09	0.833907	0.998981	0.967614	0.925083	0.975735	0.954780	1.008330	1.019815	1.006209	1.011728
2003	194.94	0.759557	0.998458	0.951373	0.888776	0.963489	0.932332	1.006356	1.015100	1.004739	1.008945
							Average	1.007271	1.017290	1.005420	1.010236

Snake River Steelhead

An analysis was conducted to develop a quantitative relationship between flow and reservoir pool survival for listed steelhead stocks. The method consisted of examining the relationship between pool survival and flow for both the Snake River reach (Lower Granite to Ice Harbor Dam) and the lower Columbia River reach (McNary to Bonneville Dam). Only empirically derived reach survival estimates were used over the 1994-2003 study period. The pool survival data were derived from a retrospective SIMPAS modeling analysis (Table 3). For each year, route-specific historic dam passage and survival data were used to determine the individual dam survivals for that year. Dividing the empirical reach survival for each project by the dam survival provided a year specific pool survival estimate for each project. [2]

Table 3. Retrospective pool survivals and flows by year with bolded survival values based on empirical data.

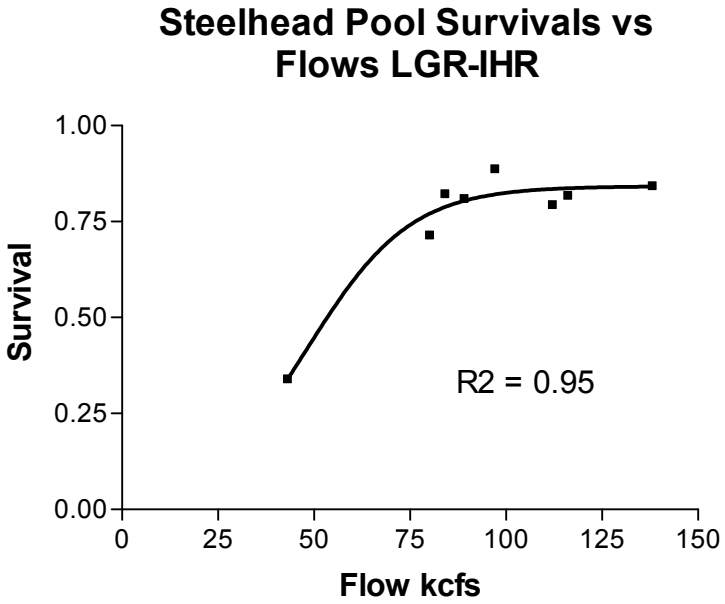
Pool Survivals - Steelhead Retro Analysis

Project	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
LGR	0.9188	**0.9787**	**0.9567**	**0.9880**	**0.9474**	**0.9297**	**0.9881**	**0.9348**	**0.9335**	**0.9584**
LGS	**0.8753**	**0.9325**	**0.9594**	**0.9893**	**0.9550**	**0.9519**	**0.9240**	**0.8482**	**0.9011**	**0.9723**
LMN	**0.9602**	**1.0000**	**1.0000**	**0.9597**	**0.9495**	**0.9778**	**0.9614**	**0.7717**	**0.9602**	**0.9887**
IHR	1.0000	**0.9727**	**0.9197**	**0.9461**	**0.9250**	**0.9461**	**0.9375**	**0.5562**	**0.8854**	**0.8792**
MCN	1.0000	**0.9963**	**0.9514**	**0.9760**	**0.9587**	**0.9787**	**0.9875**	**0.6037**	**0.8414**	**0.9361**
JDA	0.9718	0.9234	0.8847	0.9076	**0.8671**	**0.9634**	**0.8884**	**0.3686**	**0.8804**	**0.9168**
TDA	0.8977	0.9653	0.9523	0.9600	**1.0000**	**0.9070**	**0.9521**	**0.9577**	**0.8577**	**0.8701**
BON	0.8494	0.9801	0.9556	0.9701	**1.0000**	**0.8810**	**0.9286**	**0.9192**	**0.8185**	**0.8289**
Observed seasonal average flows for each reach:										
LSN	58	97	138	158	112	116	84	43	80	89
LCO	186	249	360	441	285	303	254	120	277	242

The Snake River and lower Columbia River reach pool survival estimates were determined as the product of the four pool survivals of the respective project reaches. Flows used in the retrospective analysis were observed seasonal average flows for the years 1994-2003. Flows used in the proposed and reference analyses were developed through hydrologic modeling using BPA's HYDSIM model. A regression analysis was performed using PRISM software to fit a curve to the seasonal average flows and the composite pool survival values for each reach (Figure 3). In this analysis, the best fit function for the Snake River and lower Columbia River reaches was a Boltzmann sigmoid curve. The sigmoid relationship was set to pass through zero survival so that juvenile fish survival was near zero at very low flows. Several commenters indicated that the Snake and Columbia Rivers never have zero flow – this is true. However, zero flow would not provide survival of juvenile anadromous fish to the ocean and, thus, is considered to be a valid part of the relationship. Also, the curve is not extended outside the range

[2] The year 1997 was removed from the flow/survival analysis because high levels of debris at the dams occurred that year, which decreased juvenile fish survival at the dams but not necessarily in the pools. Since pool survival is derived from the dam survival estimate, exclusion of the year 1997 was deemed appropriate.

of empirical data to zero survival. The sigmoid curve was considered to be an appropriate model to describe the relationship between flow and survival for this species in Williams *et al.* (2004). The shape of the curve indicates there is a rapid increase in survival with increasing flow at lower flows, after which survival changes little with increasing flow.



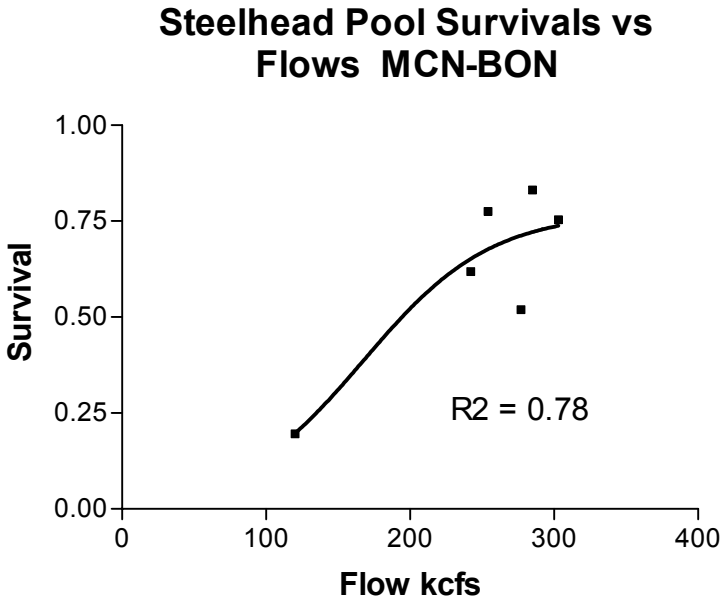


Figure 3. Relationship between flow and survival for juvenile steelhead through Lower Snake River and Lower Columbia River reaches.

The steps used to conduct the analysis follow the sequence of columns in Table 4. The sequence of calculations was:

1) Using the curve fitting function described above, annual juvenile spring chinook reach survival estimates (pools only) were calculated for both the proposed flows and reference flows for the lower Snake River and lower Columbia River reaches.

2) Individual pool survival estimates were obtained from the respective reaches by taking the fourth root of the reach survival estimates.

3) The annual proposed operation pool survivals were divided by the retrospective pool survivals and the reference operation pool survival values divided by the proposed hydro operation pool survival values to obtain an adjustment factor for use in SIMPAS pool survival in the gap analysis.

Table 4. Flow and estimated survival (pools by reach and individual pools) of juvenile steelhead by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches. (An adjustment to flow was made by operating the LCO pools at minimum operating elevations for the reference operation.)

Steelhead **POOL SURVIVALS VS FLOWS** Chris Ross
10/27/04

Boltzmann Sigmoid Lower Snake		**Boltzmann Sigmoid Lower Columbia**	
Bottom	0	Bottom	0
Top	0.8422	Top	0.7723
V50	48.37	V50	167.5
Slope	13.35	Slope	44.28

	Retrospective		**Proposed**				**Reference**	
	Reach Survival							
Year	LSN	LCO	Flow LSN	Survival LSN	Flow LCO	Survival LCO	Flow LSN	Survival LSN
1994	0.772270	0.740994	56.03	0.538701	162.02	0.362286	60.73	0.603213
1995	0.887653	0.8703454	93.60	0.814684	244.38	0.656615	95.69	0.818558
1996	0.844131	0.7660098	125.12	0.839525	315.89	0.746152	126.32	0.839754
1997	0.887351	0.8249366	145.37	0.841612	401.76	0.768427	147.77	0.841708
1998	0.794695	0.8313368	105.29	0.830514	257.84	0.683450	107.51	0.832286
1999	0.818698	0.7534536	112.74	0.835472	310.88	0.743138	114.52	0.836308
2000	0.822924	0.7756777	80.02	0.770253	246.25	0.660707	82.84	0.782969
2001	0.340380	0.1959073	53.99	0.508450	155.53	0.334272	56.74	0.548943
2002	0.715137	0.5199787	84.80	0.790579	256.09	0.680295	86.50	0.796428
2003	0.810038	0.6189625	73.32	0.729625	194.94	0.502110	76.52	0.751009

Table 4. Flow and estimated survival (pools by reach and individual pools) of juvenile steelhead by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

	Retrospective		**Proposed**	**Proposed**	**Reference**
Year	4th Root LSN	4th Root LCO	4th Root LSN	4th Root LCO	4th Root ls
1994	0.937437	0.927799	0.856716	0.775823	0.881288
1995	0.970646	0.965879	0.950052	0.900176	0.951179
1996	0.958523	0.935532	0.957213	0.929409	0.957278
1997	0.970563	0.953027	0.957807	0.936269	0.957834
1998	0.944170	0.954870	0.954634	0.909236	0.955142
1999	0.951220	0.931674	0.956055	0.928469	0.956294
2000	0.952445	0.938470	0.936825	0.901576	0.940668
2001	0.763820	0.665293	0.844427	0.760370	0.860759
2002	0.919596	0.849173	0.942945	0.908185	0.944684
2003	0.948694	0.886985	0.924219	0.841782	0.930918

	Ratio of Proposed to Retro (adjust. Factors)		**Ratio of Reference to Proposed (adjust. Factors)**
Year	Lower Snake	Lower Columbia	Lower Snake
1994	0.913892	0.836198	1.028681
1995	0.978783	0.931976	1.001187
1996	0.998633	0.993455	1.000068
1997	0.986857	0.982416	1.000029
1998	1.011083	0.952209	1.000533
1999	1.005083	0.996560	1.000250
2000	0.983600	0.960687	1.004102
2001	1.105532	1.142911	1.019342
2002	1.025390	1.069493	1.001844
2003	0.974201	0.949038	1.007248

Table 4. Flow and estimated survival (pools by reach and individual pools) of juvenile steelhead by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

Steelhead **POOL SURVIVALS VS FLOW Adjustments for MOP Operation in Lower Columbia R.** JR/CR 10/25/2004

Boltzmann Sigmoid
Lower Columbia

Bottom	0
Top	0.7723
V50	167.5
Slope	44.28

Pool	Avg normal	At MOP
MCN	1300	1166
JDA	2325	1990
TDA	318	277
BON	795	715
LC Vol.(Kaf)	4738	4148

Avg normal to MOP ratio: **1.142237**

Year	Reference Flows LCO	Adjusted LCO Flow	Adjusted Survival LCO	Adj Survival per mile LCO	Adj Survival MCN pool (32.3 miles)	Adj Survival JDA pool (76.4 miles)	Adj Survival TDA pool (24.1 miles)	Adj Survival BON pool (45.4 miles)
1994	161.39	184.34	0.458714	0.995636	0.868265	0.715966	0.899967	0.819919
1995	249.22	284.67	0.721147	0.998167	0.942466	0.869221	0.956751	0.920087
1996	324.57	370.74	0.764537	0.998494	0.952500	0.891270	0.964341	0.933885
1997	421.76	481.75	0.771661	0.998546	0.954103	0.894821	0.965552	0.936095
1998	272.17	310.88	0.743141	0.998335	0.947613	0.880490	0.960646	0.927156
1999	323.44	369.44	0.764308	0.998493	0.952449	0.891156	0.964302	0.933814
2000	256.18	292.62	0.729088	0.998228	0.944339	0.873312	0.958169	0.922657
2001	151.82	173.41	0.411893	0.995035	0.851485	0.683669	0.886958	0.797735
2002	269.32	307.63	0.741006	0.998319	0.947118	0.879404	0.960273	0.926477
2003	187.13	213.75	0.571283	0.996863	0.903499	0.786601	0.927078	0.867068

Table 4. Flow and estimated survival (pools by reach and individual pools) of juvenile steelhead by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

Year	**Proposed** Flows LCO	Survival LCO	Adj Survival per mile LCO	Adj Survival MCN pool	Adj Survival JDA pool	Adj Survival TDA pool	Adj Survival BON pool	Ref. survival ratio-- MCN	Ref. survival ratio-- JDA	Ref. survival ratio-- TDA	Ref. survival ratio-- BON
1994	162.02	0.3623	0.994312	0.833160	0.646754	0.871562	0.771851	1.042135	1.107015	1.032590	1.062277
1995	244.38	0.6566	0.997640	0.927165	0.834809	0.944637	0.898264	1.016504	1.041221	1.012824	1.024294
1996	315.89	0.7462	0.998356	0.948719	0.881893	0.961129	0.928034	1.003986	1.010633	1.003342	1.006305
1997	401.76	0.7684	0.998521	0.953749	0.893098	0.964965	0.935023	1.000371	1.001929	1.000608	1.001146
1998	257.84	0.6834	0.997864	0.933865	0.849286	0.949774	0.907488	1.014721	1.036741	1.011447	1.021673
1999	310.88	0.7431	0.998334	0.948029	0.880362	0.960602	0.927076	1.004662	1.012260	1.003851	1.007267
2000	246.25	0.6607	0.997674	0.928201	0.837039	0.945432	0.899689	1.017386	1.043335	1.013472	1.025530
2001	155.53	0.3343	0.993863	0.821193	0.624795	0.862117	0.756169	1.036888	1.094229	1.028813	1.054969
2002	256.09	0.6803	0.997838	0.933089	0.847601	0.949179	0.906418	1.015036	1.037522	1.011687	1.022130
2003	194.94	0.5021	0.996137	0.883509	0.744010	0.910941	0.838855	1.022626	1.057245	1.017715	1.033633
							Average	1.017431	1.044213	1.013635	1.025922

Snake River Fall Chinook Salmon

An analysis was conducted to develop a quantitative relationship between flow and reservoir pool survival for listed fall chinook salmon stocks. The method consisted of examining the relationship between pool survivals and flows for both the Snake River reach (Lower Granite to Ice Harbor Dam) and the lower Columbia River reach (McNary to Bonneville Dam). Only empirically derived reach survival estimates for the Snake River reach were used over the 1995-2001 and 2003 study period . Empirical reach survival estimates were not available for 1994 or 2002 for either reach. For each remaining year, route-specific dam passage and survival data were used to determine the individual project survivals for that year. The pool survival data were derived from a retrospective SIMPAS modeling analysis (Table 5). Dividing the empirical survival for each project by the dam survival provided a year-specific pool survival estimate for each project. No empirical reach survival data were available below Lower Monumental Dam in 1995 and 1996. Therefore, these years were not included in the lower Snake River section of the analysis. No empirical survival data were available in the lower Columbia River reach for any year. Thus, to complete the system-wide analysis, the lower Snake River survival rates were extrapolated to the lower Columbia reach using a survival-per-mile method.[3]

Table 5. Retrospective pool survivals and flows by year with bolded survival values based on empirical data.

Pool Survivals - Subyearling Chinook Retro Analysis

Project	1995	1996	1997	1998	1999	2000	2001	2003
LGR	**0.7084**	**0.5041**	**0.3724**	**0.5962**	**0.7440**	**0.5062**	**0.2228**	**0.5497**
LGS	**0.9124**	**0.9380**	**0.5945**	**0.8236**	**0.7449**	**0.8224**	**0.8108**	**0.8818**
LMN	**0.8462**	**0.8394**	**0.6858**	**0.9978**	**0.8976**	**0.8238**	**0.7598**	**0.8889**
IHR	0.9830	0.9924	**0.8914**	**0.9574**	**0.9404**	**0.9761**	**0.7704**	**0.8935**
MCN	1.0000	1.0000	**0.9496**	**0.9699**	**0.9185**	**0.9965**	**0.8411**	**0.9825**
JDA	0.7409	0.7580	0.5591	0.8626	0.7408	0.7962	0.6054	0.8153
TDA	0.9097	0.9163	0.8324	0.9545	0.9097	0.9306	0.8536	0.9376
BON	0.8377	0.8491	0.7095	0.9165	0.8377	0.8741	0.7436	0.8864
Observed seasonal average flows for each reach:								
LSN	97	138	158	112	116	84	43	89
LCO	249	360	441	285	303	254	120	242

The Snake River and lower Columbia River reach survival estimates were determined as the product of the four pool survivals of the respective river reaches. Flows used in the retrospective analysis were observed seasonal average flows for the years 1995-2001 and 2003. Flows used in the proposed and reference operations were developed through hydrologic modeling using BPA's HYDSIM model. A regression analysis was performed using PRISM software to fit a curve to the seasonal average flows and reach survival values (Figure 4). The best fit function for

[3] The year 1997 was removed from the flow/survival analysis for both the lower Snake and lower Columbia reaches because of high levels of debris at the dams that year, which decreased juvenile fish survival at the dams but not necessarily in the pools. Since pool survival is derived from the dam survival estimate, exclusion of the year 1997 was deemed appropriate.

the Snake River reach was a Boltzmann sigmoid curve. The sigmoid relationship was set to pass through zero survival so that juvenile fish survival was near zero at very low flows. Several commenters indicated that the Snake and Columbia Rivers never have zero flow – this is true. However, zero flow would not provide survival of juvenile anadromous fish to the ocean and is considered to be a valid part of the relationship. Also, the curve is not extended outside the range of empirical data to zero survival. The sigmoid curve was considered to be an appropriate model to describe the flow-survival relationship for subyearling fall chinook salmon in the lower Snake River (Smith *et al.* 2003). The shape of the curve indicates there is a rapid increase in survival with increasing flow at lower flows, after which survival changes little with increasing flow. For the Columbia River reach, the best fit curve was a one-phase exponential association. This curve passes through 0,0 in the regression, consistent with the assumption that zero flow equals zero survival The shape of the curve indicates a reduction in the rate of increasing juvenile fish pool survival with higher flows, consistent with other analyses (Williams et al. 2004).

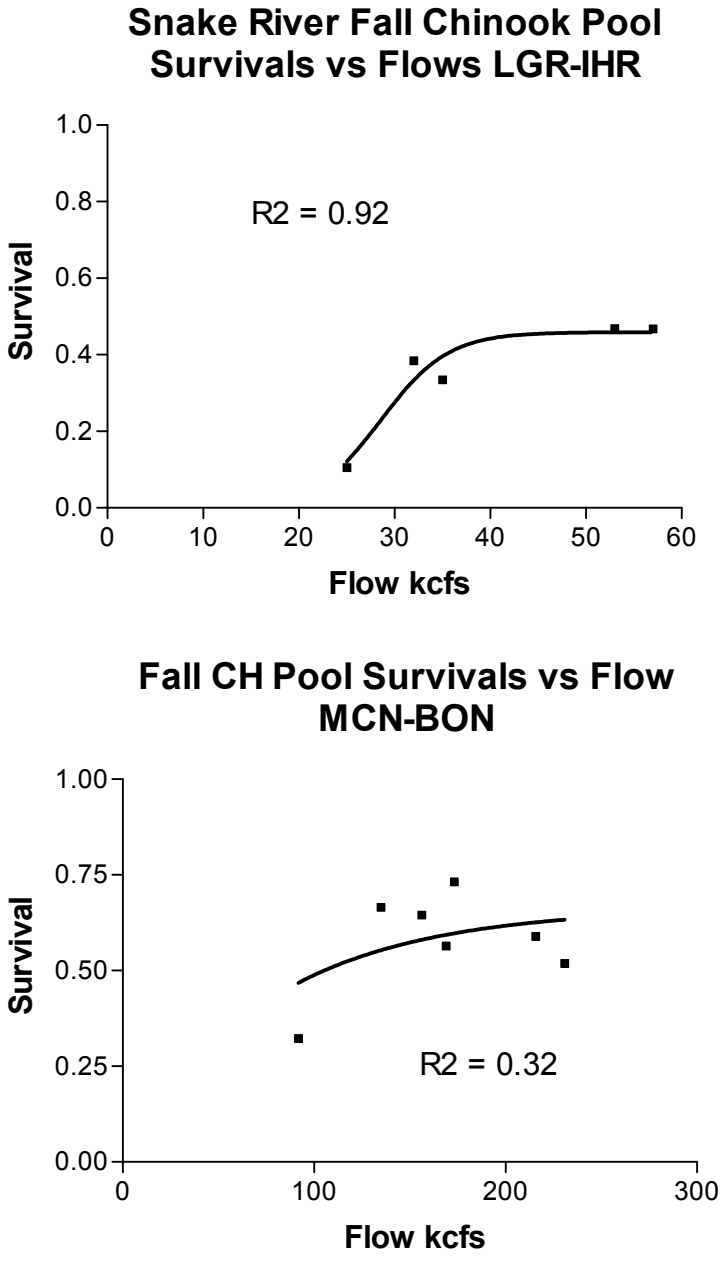


Figure 4. Relationship between flow and pool survival for juvenile Snake River fall chinook salmon through lower Snake River and lower Columbia River reaches.

This analysis was specific to juvenile fall chinook that exhibit a subyearling life history. Both a yearling and subyearling life history have been demonstrated by juvenile Snake River fall chinook salmon (Smith *et al*. 2002). Little specific information is known about the yearling life history of these fish at this time. However, it appears that those fish that exhibit the yearling life history make up a substantial percentage of the adult returns to Lower Granite Dam (Connor *et al*. 2004). Given the existence of the yearling life history, the empirical reach survival data for Snake River fall Chinook could be providing conservative survival estimates, because it assumes that fish not observed at downstream projects are mortalities, when these fish could have survived and migrated downstream later as yearling migrants.

The steps used to conduct the analysis follow the sequence of columns in Table 6. The sequence of calculations was:

1) Using the curve fitting function described above, annual juvenile fall chinook reach survival estimates (pools only) were calculated for both the proposed flows and reference flows for the lower Snake and Columbia River reaches.

2) Individual pool survival estimates were obtained from the respective reaches by taking the fourth root of the reach survival estimates.

3) The annual proposed operation pool survivals were divided by the retrospective pool survivals and the reference operation pool survival values divided by the proposed hydro operation pool survival values to obtain an adjustment factor for use in SIMPAS pool survival in the "gap" analysis.

Table 6. Flow and estimated survival (pools by reach and individual pools) of juvenile fall chinook by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches. (An adjustment to flow was made by operating the LCO pools at minimum operating elevations for the reference operation.

Fall Chinook **POOL SURVIVALS VS FLOWS** Chris Ross
10/27/04

Boltzmann Sigmoid

	L Snake
Bottom	0
Top	0.4593
V50	28.59
Slope	3.512

Exponential Association

	L Columbia
YMAX	0.6635
K	0.01331

	Retrospective		Proposed				Reference	
	Reach Survival							
Year	LSN	LCO	Flow LSN	Survival LSN	Flow LCO	Survival LCO	Flow LSN	Survival LSN
1995	0.537649	0.564634	43.55	0.4529	139.05	0.5593	47.2	0.4570
1996	0.393866	0.589709	54.92	0.4590	190.12	0.6107	57.9	0.4592
1997	0.135338	0.313539	61.61	0.4593	197.51	0.6156	64.8	0.4593
1998	0.469103	0.731809	44.75	0.4547	135.99	0.5549	47.6	0.4573
1999	0.467787	0.518450	48.94	0.4579	184.47	0.6065	54.5	0.4590
2000	0.334730	0.645452	35.15	0.3979	131.60	0.5484	37.8	0.4282
2001	0.105733	0.323188	26.91	0.1757	114.72	0.5194	26.9	0.1754
2003	0.384990	0.665714	35.29	0.3999	128.83	0.5441	39	0.4349

	Retrospective		Proposed	Proposed	Reference
Year	4^{th} Root LSN	4^{th} Root LCO	4^{th} Root LSN	4^{th} Root LCO	4^{th} Root LSN
1995	0.856298	0.866846	0.820354	0.864774	0.822210
1996	0.792204	0.876313	0.823121	0.883999	0.823187
1997	0.606533	0.748295	0.823219	0.885785	0.823229
1998	0.827593	0.924910	0.821182	0.863095	0.822320
1999	0.827012	0.848549	0.822610	0.882503	0.823107
2000	0.760630	0.896326	0.794201	0.860540	0.808932
2001	0.570234	0.753987	0.647473	0.848930	0.647188
2003	0.787703	0.903279	0.795242	0.858839	0.812057

Table 6. Flow and estimated survival (pools by reach and individual pools) of juvenile fall chinook by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

	Ratio of Proposed to Retro (adjust. Factors)		**Ratio of Reference to Proposed (adjust. Factors)**
Year	Lower Snake	Lower Columbia	Lower Snake
1995	0.958024	0.997610	1.002263
1996	1.039027	1.008770	1.000079
1997	1.357252	1.183737	1.000012
1998	0.992254	0.933166	1.001386
1999	0.994677	1.040015	1.000604
2000	1.044135	0.960075	1.018549
2001	1.135452	1.125921	0.999560
2003	1.009572	0.950801	1.021145

Table 6. Flow and estimated survival (pools by reach and individual pools) of juvenile fall chinook by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

Fall Chinook **POOL SURVIVALS VS FLOW Adjustments for MOP Operation in Lower Columbia River**

JR/CR
10/25/2004

Ex. Association

Lower Columbia

YMAX	0.6635
K	0.01331

Pool	Avg normal	At MOP
MCN	1300	1166
JDA	2325	1990
TDA	318	277
BON	795	715
LC Vol.(Kaf)	4738	4148

Avg normal to MOP ratio: **1.142237**

Year	Reference Flows LCO	Adjusted LCO Flow	Adjusted Survival LCO	Adj Survival per mile LCO	Adj Survival MCN pool (32.3 miles)	Adj Survival JDA pool (76.4 miles)	Adj Survival TDA pool (24.1 miles)	Adj Survival BON pool (45.4 miles)
1995	178.7	204.12	0.619652	0.997318	0.916907	0.814493	0.937324	0.885209
1996	213.4	243.75	0.637628	0.997478	0.921672	0.824540	0.940956	0.891681
1997	220.0	251.29	0.640098	0.997500	0.922318	0.825908	0.941448	0.892560
1998	177.7	202.98	0.618981	0.997312	0.916727	0.814114	0.937187	0.884964
1999	209.6	239.41	0.636089	0.997464	0.921269	0.823686	0.940649	0.891132
2000	177.3	202.52	0.618709	0.997309	0.916654	0.813961	0.937131	0.884865
2001	166.0	189.61	0.610314	0.997233	0.914387	0.809207	0.935401	0.881790
2003	175.2	200.12	0.617256	0.997296	0.916263	0.813141	0.936833	0.884335

Table 6. Flow and estimated survival (pools by reach and individual pools) of juvenile fall chinook by year for the lower Snake (LSN) and lower Columbia (LCO) river reaches (continued)

Year	**Proposed** Flows LCO	Survival LCO	Adj Survival per mile LCO	Adj Survival MCN pool	Adj Survival JDA pool	Adj Survival TDA pool	Adj Survival BON pool	Ref. survival ratio-- MCN	Ref. survival ratio-- JDA	Ref. survival ratio-- TDA	Ref. survival ratio-- BON
1995	139.05	0.559257	0.996744	0.900021	0.779458	0.924414	0.862381	1.018762	1.044947	1.013966	1.026471
1996	190.12	0.610670	0.997236	0.914484	0.809410	0.935475	0.881922	1.007861	1.018693	1.005859	1.011066
1997	197.51	0.615620	0.997281	0.915823	0.812216	0.936497	0.883737	1.007093	1.016857	1.005287	1.009983
1998	135.99	0.554925	0.996701	0.898754	0.776864	0.923443	0.860674	1.019998	1.047950	1.014884	1.028222
1999	184.47	0.606548	0.997198	0.913362	0.807063	0.934619	0.880401	1.008657	1.020597	1.006452	1.012189
2000	131.60	0.548384	0.996634	0.896824	0.772925	0.921963	0.858078	1.022111	1.053092	1.016452	1.031218
2001	114.72	0.519382	0.996330	0.888035	0.755127	0.915213	0.846281	1.029675	1.071617	1.022059	1.041959
2003	128.83	0.544059	0.996590	0.895538	0.770306	0.920976	0.856349	1.023143	1.055608	1.017218	1.032681
							Average	1.017162	1.041170	1.012772	1.024224

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